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VOLUME XXIII NUMBER 3

THE
JOURNAL OF GEOLOGY

APRIL-MAY 1915

POST-CRETACEOUS HISTORY OF THE MOUNTAINS OF CENTRAL WESTERN WYOMING

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PART II

Later Tertiary planation.—Whether or not the early Tertiary formations ever covered the entire district, it is evident that they have been stripped from large areas which they formerly occupied; for scattered outliers are now situated several miles beyond the edge of the continuous outcrop. It is also an obvious fact that large quantities of the original Tertiary strata have been carried away by erosion in the broad basins themselves. The deformation which succeeded the laying-down of the sediments, probably about the middle of the Miocene, must have initiated a new cycle of erosion, and subjected to denudation large tracts which had previously been sites of aggradation. In later pages it will be shown that between the Miocene and the present there have been several erosion cycles, and the interpretation of those cycles forms an important part of this essay. The data for this must be drawn largely from the features of the existing topography, now to be considered.

The central part of the Wind River Range is in reality a broad dissected plateau 20–30 miles wide, surmounted by a narrow axial range of sharp peaks. The plateau is no longer complete but rather consists of numerous tabular remnants,[1] which the eye can easily combine and thus reconstruct in imagination the original surface (Figs. 12, 13, 14). Such a reconstruction suggests a region reduced largely to flatness, but with subdued mountains and hills with a relief of less than 1,500 feet near the divide, i.e., a state of early old age. The topography was largely independent of rock structure, passing indiscriminately across hard and soft members of the Archean complex and also across the alternately hard and soft Paleozoic strata. In 1909 this was recognized as a peneplain by C. L. Baker;[2] and Westgate and Branson[3] in a later paper described a similar feature at the

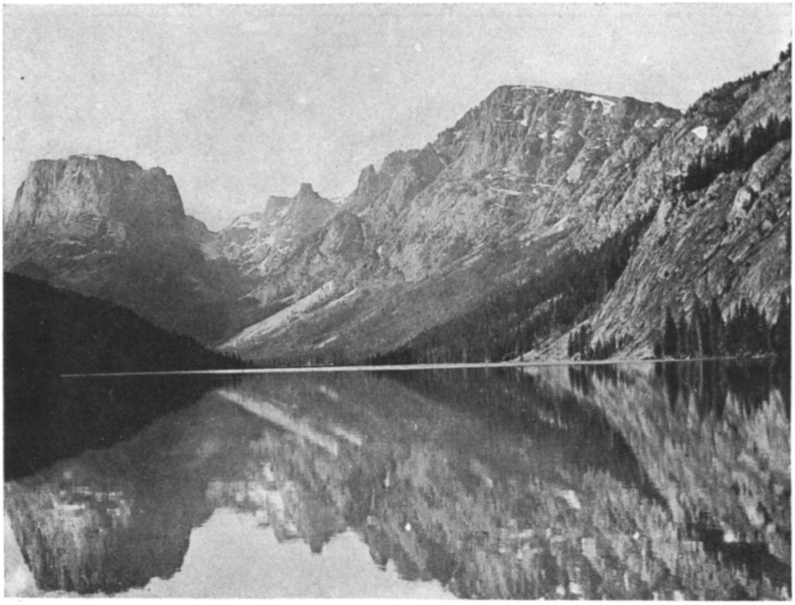

FIG. 12.—Photograph of Green River lakes and Square Top Mountain, a remnant of the summit peneplain. Photograph by C. L. Baker.

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[1] See the Fremont Peak, Wyoming, topographic sheet of the U.S. Geological Survey.

[2] C. L. Baker, "Cenozoic History of Western Wyoming," *Bull. Geol. Soc. Am.*, XXIII (1912), 73 (abstract).

[3] L. G. Westgate and E. B. Branson, "Later Cenozoic History of the Wind River Mountains," *Jour. Geol.*, XXI (1913), 142–59.

southeast end of the Wind River Range. Instead of assuming the origin of the plain, it is fitting that we examine the question before proceeding.

It is apparent that the plateau surface is a cut plain, with residual hills and mountains still standing above it. There appear to be three methods by which extensive cut plains may be produced in the interior of a continent: (*a*) by the action of ice-sheets;[1] (*b*) by the long-continued action of the wind; (*c*) by river systems that have endured to old age.

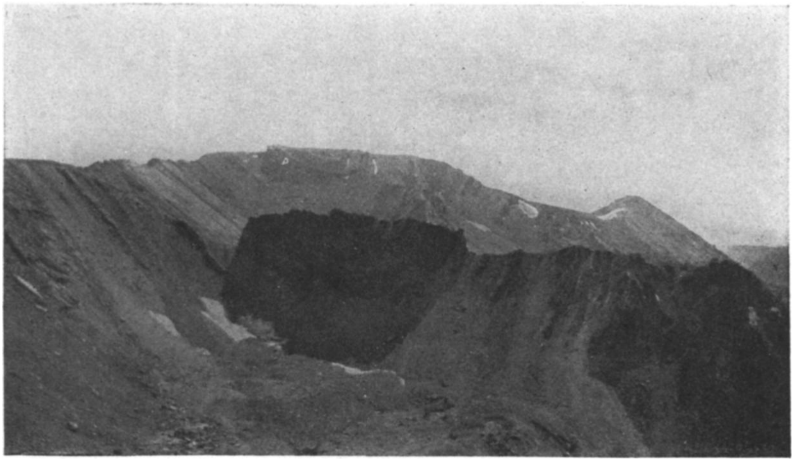

FIG. 13.—Mountain ridge (11,500 feet) near Gypsum Creek at the west end of the Wind River Range, showing a syncline in Paleozoic rocks cut off at the level of the peneplain.

There is so little in favor of the hypothesis that the plain was produced by ice-sheet glaciation, that it may be quickly dismissed. It will be shown that the plain is one of the oldest topographic features in the district and therefore probably pre-Quaternary. It now carries locally upon its surface deposits of residual soil. There is no evidence of general ice-sheet glaciation in the surrounding districts. It would have to be assumed that the present axial range has been developed since the ice sheet disappeared, for ice sheets inevitably tend to destroy rather than to make such features, and would almost surely succeed if they persisted so long as to planate the surroundings.

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[1] F. E. Wright, "Effects of Glacial Action in Iceland," *Bull. Geol. Soc. Am.*, XXI (1910), 717-30.

It seems to be established that prolonged wind abrasion in deserts does produce plains on which only scattered elevations remain; although the criteria for recognizing ancient wind-made plains are hardly as well agreed upon by physiographers as are the criteria for peneplains. Such a plain, if undefaced, should have certain characteristic features which could be used in recognizing its origin. Its depressions should be broad, relatively flat-bottomed hollows, rather than graded valleys, and these hollows should have a definite relation to the weakest rocks. Wherever hard and soft rocks are exposed there should be the characteristic wind-etched ridges, ledges, mushroom rocks, etc. The pebbles in the gravel strewn upon the flats by occasional floods should be pitted, polished, and even beveled by the sand-blast. Only the most massive and resistant bodies of rock should stand out as hills and mountains.

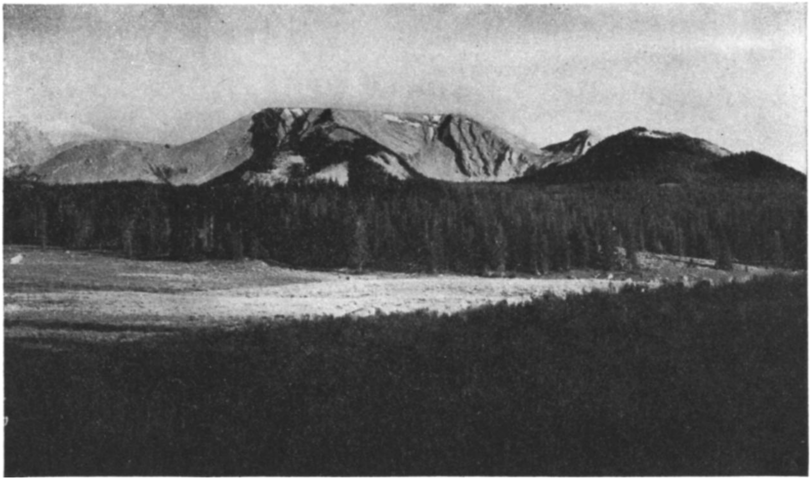

FIG. 14.—Photograph of mountain (11,500 feet) near Gypsum Creek. Tilted Paleozoic limestones trunkated at summit.

Unfortunately it is almost impossible to apply the test of these criteria to the Wind River plateau in its present condition. The details of its surface forms and material have been greatly modified by the long-continued action of frost above timber-line. The trenching of the plateau by many canyons, and especially the scouring of its surface by widespread alpine glaciers in a comparatively recent epoch, have generally effaced the original details of its topography. The higher mountain peaks do not, however, appear to have any relation to especially hard rocks, but rather form a definite range or divide near the crest of the anticline. In short, if the plain was largely fashioned by wind action, all evidence of the fact seems to have disappeared.

The competency of streams to reduce hard and soft rocks alike to monotonous relief, without removing the last residual mountains, is generally admitted. Upon such a plain there should be only thin alluvial deposits and widespread residual soil. It is an observed fact that on the southwest side of the Wind River Range deposits of soil, several feet deep, due to the decay of the granitic rock in place, still exist upon the tops of mountains 11,300 feet high, which constitute a part of this or a still younger plain (Fig. 16). Since the original drainage can no longer be seen, and since in all but a few places topographic detail has been modified by subsequent glaciation, the evidence directly in favor of river erosion is but little more satisfactory than that for wind action. The most significant fact is perhaps the continuous range of peaks, forming a divide independent of rock structure. Such divides are characteristic of stream-made topographies, but of no others. As the problem now stands there is then only a measure of probability, but not proof, that streams were the agents of planation; and so, for convenience, the old plateau surface will be called in later pages a "peneplain," implying thereby only that it was produced by the long-continued action of degrading agencies.

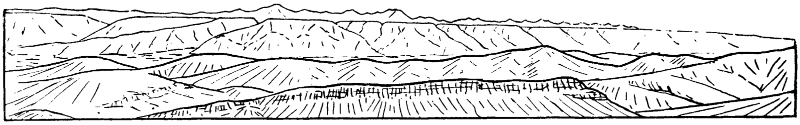

FIG. 15.—Drawing (from a photograph) of Wind River peneplain and range as seen from Triangle Peak in the Gros Ventre Range.

If reconstructed by filling the depressions cut out of it, the summit peneplain would stand forth as a gently undulating surface, surrounded by many low hills and even mountains of gentle slope, rising to a distinct divide now marked by the crest of the Wind River Range. Unmarred remnants of this surface are believed to exist still in Goat Flat, the high plateau west of West Torrey Creek, the flats both north and south of Clear Creek and other similar features ranging from about 12,000–13,000 feet in altitude, and declining near the outer borders of the range to about 11,300 feet. As a result of two or three stages of glaciation, the slopes of the once broad, residual hills and especially the axial divide have been excavated and made much steeper than before. To this process I ascribe the existing sharpness of the peaks and arêtes of the range. The broad plateau remnants at 10,000–10,500 feet east of Pinedale may not be parts of the summit peneplain, but rather the result of a later cycle.

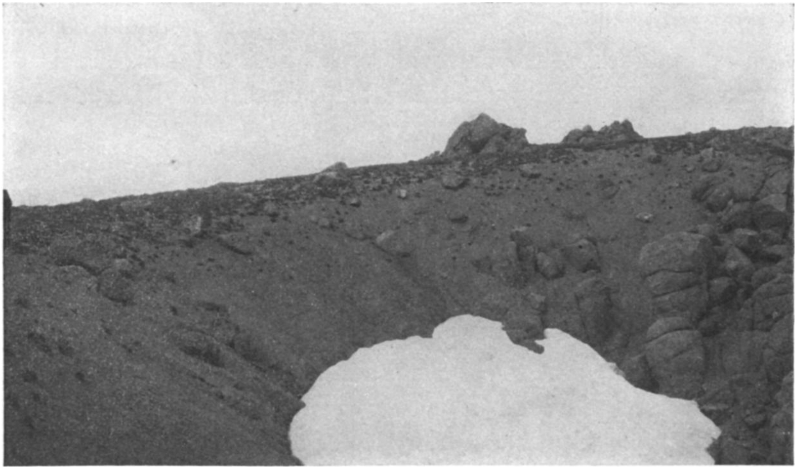

FIG. 16.—Residual soil from granite, a remnant of the Wind River peneplain, now at 11,300 feet, Gypsum Creek.

Although the ancient peneplain has since been widely demolished by erosion, other remnants of it than the Wind River plateau should exist; but a search of neighboring ranges brings unsatisfactory results. The Mount Leidy highlands, to the northwest, are so maturely dissected that no ancient flats remain at high elevations. The flats at 11,000–12,000 feet in the Absaroka Range may well belong to the same stage, but they are less significant because they lie upon horizontal strata. The more or less level crest of the Hoback Range, at 9,000–10,000 feet, is somewhat more suggestive of planation. This range consists of highly folded hard and soft rocks, which if planated and then dissected would cause the sculpturing of level-topped ridges. This type of topography prevails southward along the Wyoming Range and is conspicuous near Labarge Mountain northeast of Kemmerer. Along the crest of the Gros Ventre Range and especially in the western half there are some flats of considerable area at elevations of 10,300–10,800 feet. These have been cut across strata of varying hardness tilted at angles of 10–50° on both flanks of an anticline. However, it should be noted that they lie 1,000–2,000 feet lower than the Wind River plateau. As the mountain ridges to the southwest are considerably lower (8,000–9,500 feet), they may belong to later peneplains, unless the Wind River surface has been notably warped.

From the canvass of the district it appears that the peneplain is preserved best on the very massive hard rocks of the broad Archean outcrop in the Wind River Mountains. Somewhat doubtfully I correlate with this the smaller flats along the crests of ranges where hard folds in Paleozoic rocks have been trunkated. Over the intervening territory the weakness of the Mesozoic and Tertiary rocks has enabled the streams to destroy the peneplain.

In the Teton Range there is a broad expanse of the massive Archean formations, and hence the preservation of another large peneplain remnant might be anticipated. Instead we find an extremely rugged surface with but few small elevated flats. The east base of the range is marked by a fault of more than 10,000 feet displacement, along which the soft Cretaceous shales and Tertiary clays have been brought down to the level of the massive Archean gneiss. There is good evidence that this fault is not younger than the mid-Tertiary epoch of diastrophism. Urged by such conditions, the rejuvenated streams are believed to have rapidly excavated Jackson Hole from the Cretaceous and Eocene beds, thus leaving the Archean mass of the Tetons to form a wall of imposing height along the west (Fig. 17). Consequent streams on the face of the wall were able to cut only short steep gorges in the block, while the Snake River was rapidly excavating the adjacent beds of clay and shale. That portion of the peneplain upon the Teton block thus found itself in a position particularly vulnerable to the attack of streams and glaciers, and hence it has been carved into ruggedness more rapidly than other uplifts. Nevertheless

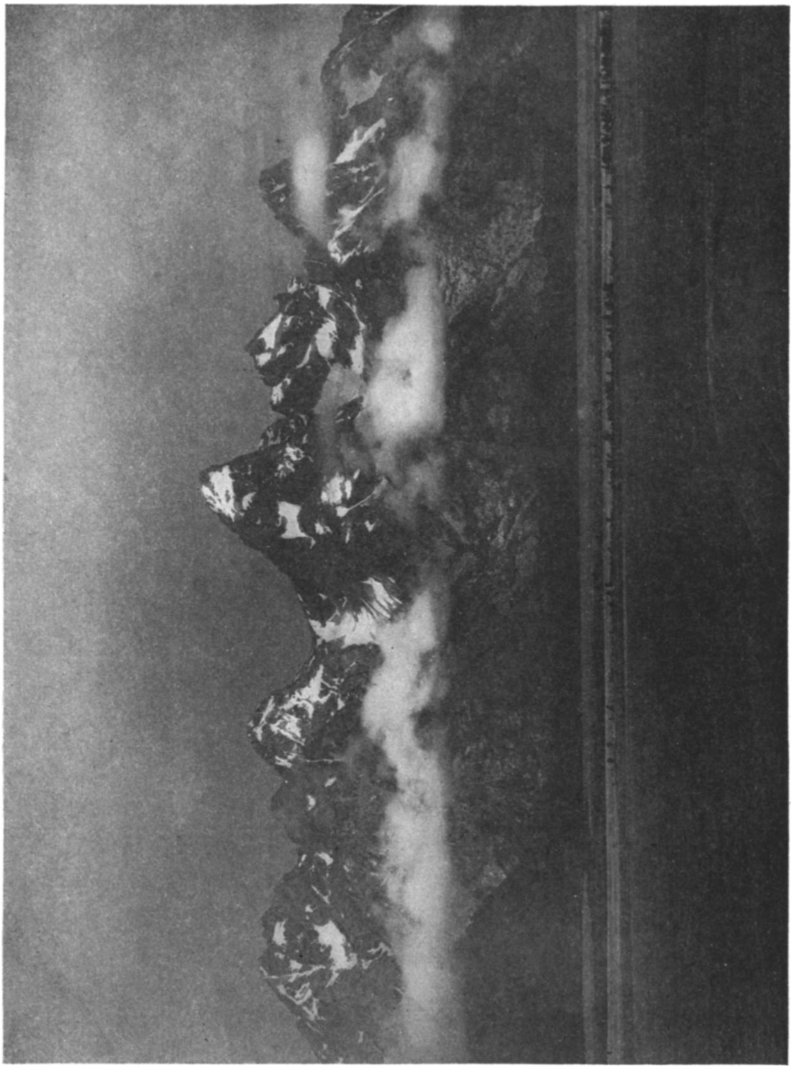

FIG. 17.—The eastern front of the Teton Range, including the Grand Teton. (Photograph by Stimson)

at least two small remnants of an apparent peneplain still exist north of the Grand Teton; one is the flattish summit of Mount Moran (12,100 feet) and the other a triangular flat summit at 10,000 feet on the north side of Birch Creek several miles to the west. Only the latter of these has ever been examined by a geologist (Figs. 18*a* and 18*b*). Its surface is strewn with the usual frost-cracked dêbris of the underlying Madison limestone, but also with well-rounded cobbles of quartzite which still retain their original polish. That this is a bit of an old stream-worn surface is thus clearly shown. It may be a part either of the Wind River or later peneplains, or of the unconformity at the base of the Pinyon conglomerate. It may be argued that the peneplain would not

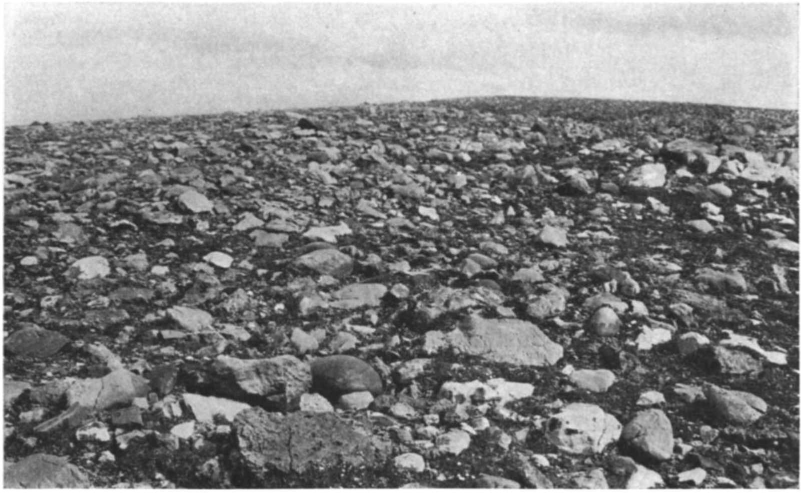

FIG. 18*a*.—Waterworn cobblės of quartzite among limestone fragments on the flat summit of a peak (10,100 feet) in the Teton Range.

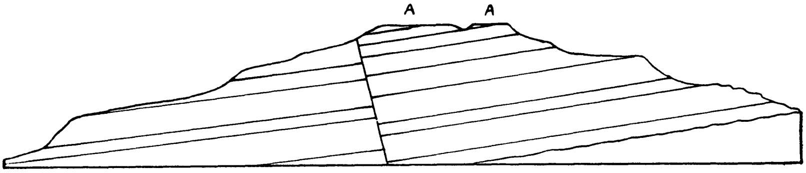

FIG. 18*b*.—Diagram of the occurrence of the gravel shown above. The gravel lies on the surfaces (*AA*).

be likely to have coarse gravel upon its surface. The surface underlying the Eocene formations, which is gravel-strewn, has already been described as being rugged.

In Yellowstone Park the formation of the peneplain may have been prevented, or if it was made, it may have been overwhelmed, by the volcanic eruptions which students of that district assign to the Pliocene and later epochs.

Turning to other parts of the Rocky Mountains, I find elevated peneplains widespread. In the Bighorn Range[1] there seems to be a similar high plateau surmounted by an axial mountain range, which, prior to the cirque-making by Quaternary glaciers, had a subdued post-mature topography. There also the eroded surface trunkates the various rock structures indiscriminately. In another place[2] I have described the peneplain which is well preserved in the Sherman Mountains of southeastern Wyoming. Other cases of somewhat similar characteristics have been reported from Colorado, Montana, Idaho, Washington, and other western states. These peneplains have been assigned to the Eocene, Miocene, and Pliocene,[3] but they are so similar in their characteristics and relations as to suggest that they may be only local remnants of a once widespread old-age surface, subsequently more or less warped.

The age of the Wind River summit peneplain is debatable, but, by a process of finessing, it may be worked out with some degree of assurance. It will be admitted by all that, since it trunkates the structures produced by the folding at the close of the Cretaceous, it must be of Cenozoic age. The stage of topographic old age, when planation is being accomplished, does not permit the accumulation of thick sedimentary deposits in the same district because the two processes are mutually exclusive. This appears to be true whether the work is done by wind or by streams. For that reason it is hardly conceivable that the peneplain could have been developed while the Eocene and Oligocene strata were being deposited to thicknesses of several thousand feet in various parts of the same region. If this inference is sound, the peneplain must have been made either just before or just after the Eocene-Oligocene epoch of deposition. We may first consider the hypothesis that the peneplain is part of the pre-Wasatch (Lower Eocene) topography.

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[1] See Plates VIII A, XXVII A, XXX, and XXI A, in "Geology of the Bighorn Mountains," by N. H. Darton, *U.S. Geol. Survey, Prof. Paper 51*, 1906.

[2] *Jour. Geol.*, XVII (1909), 429–44.

[3] See p. 194.

The eroded surface which underlies the Eocene strata is clearly exposed at many points among the ranges of western Wyoming. Where it trunkates the soft Mesozoic strata, this surface is relatively flat, but on the harder rocks nearer the axes of the ranges, it is hilly and even mountainous in relief. Thus in the southwest part of the Kirwin quadrangle, between Double Diamond ranch and Mountain Meadows, the Wind River Eocene beds rest upon an eroded surface which has a visible relief of more than 1,200 feet. Immediately upon it there generally lies a coarse conglomerate (Pinyon) of variable thickness. Northeast of the Gros Ventre Range this reaches a thickness of about 1,000 feet, and on the south side it is apparently even thicker. From these facts we seem compelled to infer that there were conspicuous hilly or mountainous tracts when the early Wasatch deposits were laid down, and that streams later leveled up the lesser inequalities with their deposits.

As a second test of the hypothesis of Eocene age, attention should be turned to the relation between the peneplain and the Eocene formations, for if those relations are clear they may decide the age of the plain. The Eocene deposits now generally lie at much lower elevations than the existing remnants of the peneplain, and the basal contact in some places is more than 6,000 feet below it. I can conceive of but three ways (Fig. 19) in which this could be brought about: (*a*) the Eocene sediments may represent the filling of Eocene valleys excavated in the peneplain; (*b*) they may be remnants of once horizontal deposits laid down upon the peneplain and now preserved by down-warping or down-faulting; or (*c*) they may be bodies of sediment, either deposited in earlier depressions or warped or faulted down, upon the surface of which, together with adjacent formations, the peneplain has subsequently developed. In the first two cases the age of the peneplain would be pre-Wasatch. In the last case it would be post-Oligocene. These three possibilities will now be examined briefly.

If the Eocene sediments were deposited in basins excavated below the peneplain, the sediments should have been derived in part from the slopes and divides of the basins themselves. On both sides of the Gros Ventre Range, however, the thick coarse conglomerate in the Lower Eocene consists not of local rocks but almost entirely of varicolored quartzite with occasional porphyries. Since there are no rocks of this character entering into the make-up of the Gros Ventre Range, these pebbles must have been imported; and the nearest appropriate outcrops are about 100 miles to the northwest.

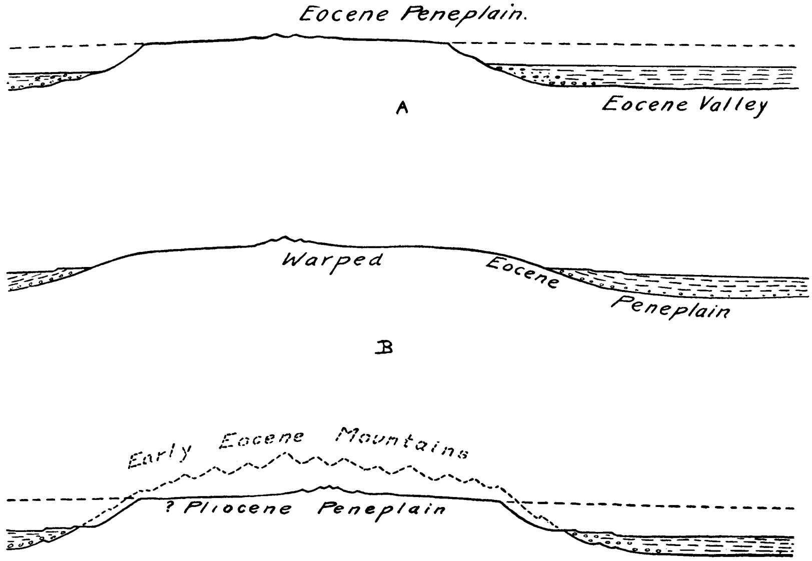

FIG. 19.—Diagrams illustrating various hypotheses as to the relation and age of the peneplain: (*a*) as an Eocene plain with valleys excavated in it and then filled; (*b*) as an Eocene plain covered with sediments and then warped; (*c*) as a Pliocene (?) plain cut across Eocene and older rocks.

Considerations of time are also somewhat adverse, since upon this hypothesis the planation, involving the most massive and resistant rocks, must have been completed in that fraction of the Eocene epoch between the folding of the Paleocene (Fort Union) strata and the deposition of the Lower Eocene (Wasatch) beds. In the same interval of time, spacious depressions must also have been excavated beneath the new peneplain for the reception of the

Eocene sediments. On the other hand, the remnants of the peneplain must have been preserved on a large scale from the early Eocene to the present. Without convincing evidence in its favor this is not, therefore, an attractive hypothesis.

On the supposition that the surface we now find beneath the Eocene sediments is part of the old peneplain, which has merely been warped and partly uncovered in subsequent time, we should anticipate that the softer Paleozoic and especially the Mesozoic strata would be reduced to base-level long before the massive granitoid rocks of the Archean were worn low. Nevertheless, there is abundant evidence that the basal Eocene surface was only maturely hilly upon the outcrops of the Paleozoic and, in some places, of even the Mesozoic strata. That surface was a plain only on the weakest beds. Again, if we are to ascribe the preservation of the Eocene to down-warping after it was deposited upon the peneplain, we should rightly expect to find the Eocene strata parallel to the base on which they rest. On the contrary, in many places they grade horizontally into thick beds of conglomerate which themselves rest against a steeply inclined surface of the older rocks, thus indicating that the beds were actually deposited in a valley or basin and not upon a plain.

To the suggestion that the peneplain is younger than the Eocene sediments, and has beveled them as well as the older rocks, I can find no objection. It is free from the difficulty occasioned by the Miocene deformation of the entire district. It explains the absence of Eocene remnants upon the peneplain and does not conflict with the existence of the rugged basal Eocene contact overlain by horizontal beds. It also corresponds with determinations in other parts of western United States, that the principal peneplains are not older than the Miocene. I therefore accept, for the present, the conclusion that the peneplain is younger than the early Tertiary strata, and later than the mid-Tertiary deformation that expressed itself in warping and faulting.

In subsequent pages it will be shown that a number of events requiring a relatively long time must be referred to the Quaternary period, and there is so much good evidence all over the western states that the opening of that period was characterized by noteworthy changes of level, that it is probably safe to refer the peneplain to the time between the Middle Miocene and these early Quaternary disturbances.

The complete planation of soft rocks may be accomplished in a geologically short time, but the reduction of very resistant granitoid rocks to a peneplain must require a vastly longer time. Planation of either kind of rocks by streams demands a constancy of conditions which is possible only when the lithosphere is in a state of rest. Inasmuch as such quiet is rarely local only, and if long continued would permit the planation of very large areas, it is worth while to inquire if peneplains were made in adjacent regions, and if so at what time geologically.

Within the past decade several geologists[1] who have independently recognized peneplains in the Rocky Mountains have referred them to late Tertiary time or specifically to the Pliocene. In several other districts somewhat more remote,—the Cascade Range of Washington,[2] the Sierra Nevada in California,[3] and the Grand Canyon of Arizona,[4]—peneplains have been reported and their ages determined as approximately Pliocene. The summit peneplain of central Idaho is assigned by Umpleby[5] to the Eocene, but in a review[6] I have suggested that the opinion is not well founded.

In brief, the evidence from all points of view here considered, although it does not establish the age of the peneplain, does strongly indicate that it was Pliocene. At that time western Wyoming must have been in a state of tectonic rest which permitted the streams or the wind, or both, to reduce nearly all of the district to the condition of a peneplain, interspersed with post-mature mountain masses, situated on the most resistant rocks (Fig. 20). Appropriately we find in the region no sediments of presumptive Miocene or Pliocene age and hence know little of the climate, the life, or the changes of the time.

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[1] W. W. Atwood and K. F. Mather, *Jour. Geol.*, XX (1912), 407; S. H. Ball, *U.S. Geol. Survey, Prof. Paper 63*, 1908, 32; E. Blackwelder, "Cenozoic History of the Laramie Region," *Jour. Geol.*, XVII (1909), 437; J. L. Rich, "Physiography of the Bishop Conglomerate, Southwestern Wyoming," *Jour. Geol.*, XVIII (1910), 613 (age given as post-Oligocene, probably Miocene); L. G. Westgate and E. B. Branson, "Cenozoic History of the Wind River Mountains," *Jour. Geol.*, XXI (1913), 144.

[2] B. Willis and G. O. Smith, "A Contribution to the Geology of the Cascade Mountains," *U.S. Geol. Survey, Prof. Paper 19*, 1903, 70.

[3] F. L. Ransome, "The Great Valley of California," Univ. of Calif., *Bull. Dept. of Geol.*, 1896, I, 371–428.

[4] H. H. Robinson, "A New Erosion Cycle in the Grand Canyon District, Arizona," *Jour. Geol.*, XVIII (1910), 742–63.

[5] J. B. Umpleby, "The Old Erosion Surface in Idaho," *Jour. Geol.*, XX (1912), 144.

[6] E. Blackwelder, "The Old Erosion Surface in Idaho: A Criticism." *Jour. Geol.*, XX (1912), 410-14.

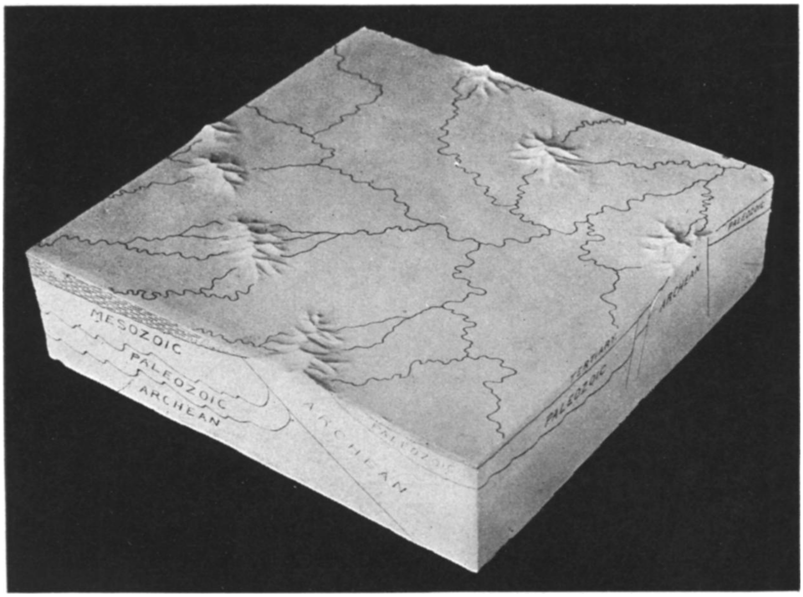

FIG. 20.—Model of a part of the Wind River basin and vicinity as it may have appeared at the completion of the peneplain.

Early Quaternary rejuvenation.—Even where now best preserved, the peneplain is trenched by deep valleys, and over a large part of the district it has been destroyed by their growth (Fig. 21). The remnants now stand at elevations (11,000–13,000 feet) so high that no agency of land sculpture seems capable of fashioning them as they stand. Since the graded streams of the district now flow in channels between 5,000 and 8,000 feet above sea-level, the remaining parts of the peneplain are obviously in a vulnerable position, and the progressive lowering of grade makes them only more so. The present altitude of the remnants may therefore be ascribed to movements in the lithosphere. Two possibilities suggest themselves: (*a*) local warpings whereby small parts of the peneplain were elevated or their surroundings were depressed; and (*b*) a widespread uniform change of level which incited the erosive agencies to excavate the soft rocks deeply, and so left only remnants of the peneplain standing out in relief, where the rocks were most resistant.

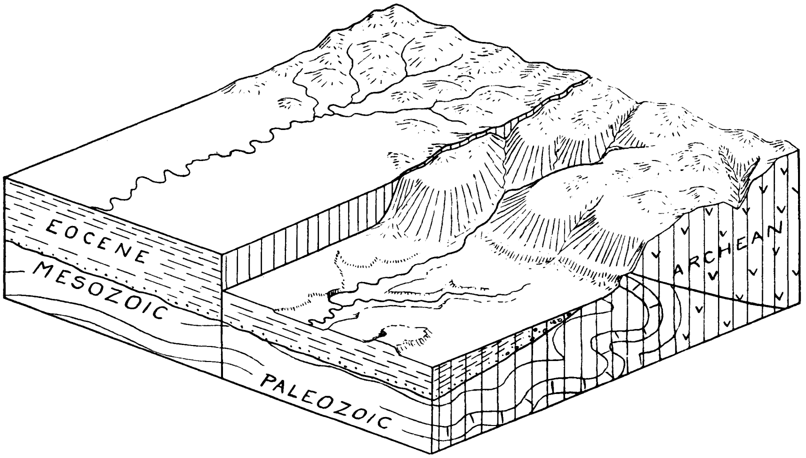

FIG. 21.—Diagram of a part of the Wind River Range before and after the dissection of the peneplain.

If the Wind River plateau be regarded as a local uplift, it may be either a horst or an upwarp (Fig. 22). That it is not the former is sufficiently indicated by the observed fact that it is not surrounded by faults. If it were an upwarp the peripheral slopes would be likely to preserve remnants of the peneplain bent downward but otherwise showing the trunkation of the various structures. I have looked carefully for such features in the foothills of the range, but with negative results. On the contrary, the peneplain comes out to the west front of the range at a nearly constant elevation and breaks off abruptly to the lowlands west of it. These facts suggest that the present contrast between the the isolated plateau and the surrounding plains is not due primarily to differential warping; but they do not preclude the possibility of warping in a minor degree.

The hypothesis that existing conditions are due to uniform regional uplift followed by selective denudation is the only one against which I find no serious objections. It agrees well with the fact that remnants of the peneplain now exist only upon the outcrops of the hardest rocks, and with the other fact that these remnants now stand at a more or less common elevation. The hypothesis of regional uplift is therefore accepted tentatively.

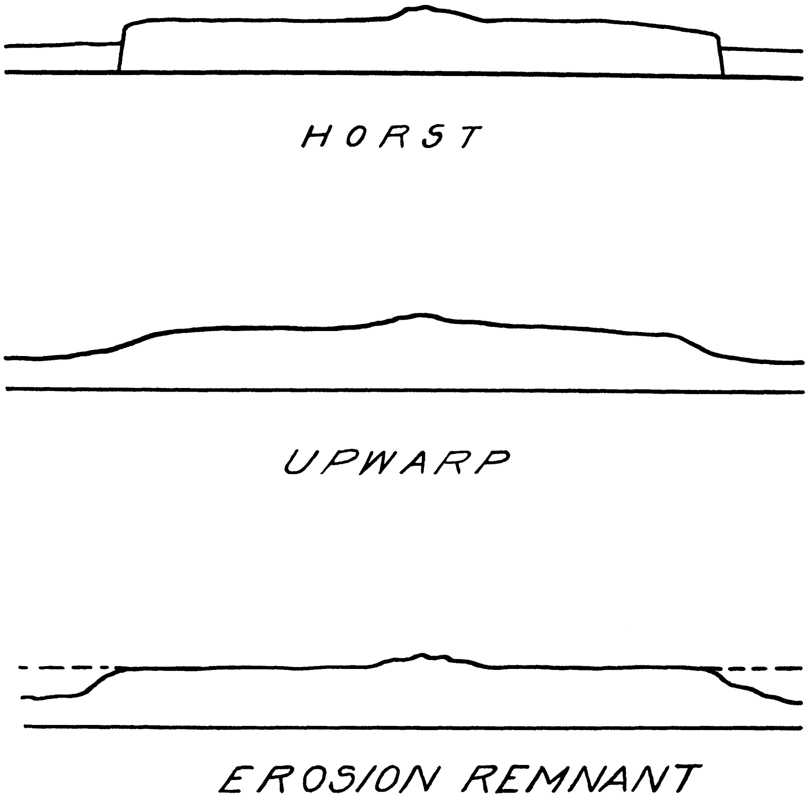

FIG. 22.—Diagrams illustrating the possible origin of the existing Wind River plateau as a horst, an unwarp, or an erosion remnant.

Local evidence alone is not sufficient to permit a close determination of the age of this elevatory movement. Obviously it followed the development of the Wind River peneplain, which the available evidence indicates occurred in the late Miocene and Pliocene. In later pages it will appear that there have been several changes of level separated by long intervals of quiet. All, however, seem to have occurred before the last stage of glaciation. It is significant that many of the geologists who have studied the western mountain states have recently concluded that the beginning of Quaternary time was marked by important changes of level, to which the present relief and ruggedness of our western mountains is in large measure due. These considerations lead to the somewhat indefinite conclusion that the several changes of level occurred between the late Pliocene and the close of the Pleistocene epoch.

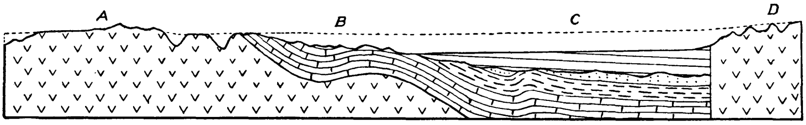

FIG. 23.—Diagram illustrating the progress of the same erosion cycle in rocks of three different degrees of hardness: (*A*) residual areas of older surface with canyons in granitic complex; (*B*) maturely mountainous surface on Paleozoic limestones, etc.; (*C*) plain on Tertiary clays: (*D*) topography of granitic mountains more advanced than at *A* because of proximity to deep basin.

General effects of erosion in the Quaternary period.—On every hand there are deep canyons, wide river basins, and other speaking evidences of denudation in geologically recent times. It is reasonable to believe that the district has been subject to erosion under slowly varying conditions and hence with varying results ever since the beginning of the uplift which seems to have accompanied the close of the Tertiary period. Although I am not disposed to belittle the efficiency of the wind in fashioning topographic details, nor in deporting dust from the region and in that way gradually lowering its elevation, it is clear from their forms that nearly all the coarser and many of the finer topographic features of western Wyoming have been carved by running water, and that in general the topography of the district has been under the control of the three principal water drainage systems—the Snake, the Green, and the Bighorn. Glaciation and eolation have merely modified the effects of erosion—the one locally, the other generally.

Before proceeding to describe the effects of stream denudation in the district, attention is called to the fact that the surface is underlain by a great variety of rocks which differ vastly in the resistance which they offer to erosive processes. Under a subarid climate, the Tertiary sandy clays are the weakest rocks; the massive Archean gneisses and granites stand near the other extreme of resistance. Between them all gradations exist. It is evident that in the softest of these materials, erosion proceeds with great rapidity in contrast with its progress upon the most refractory formations. This fact (in addition to the structure) is the key to the origin of the principal topographic features of the region (Fig. 23).

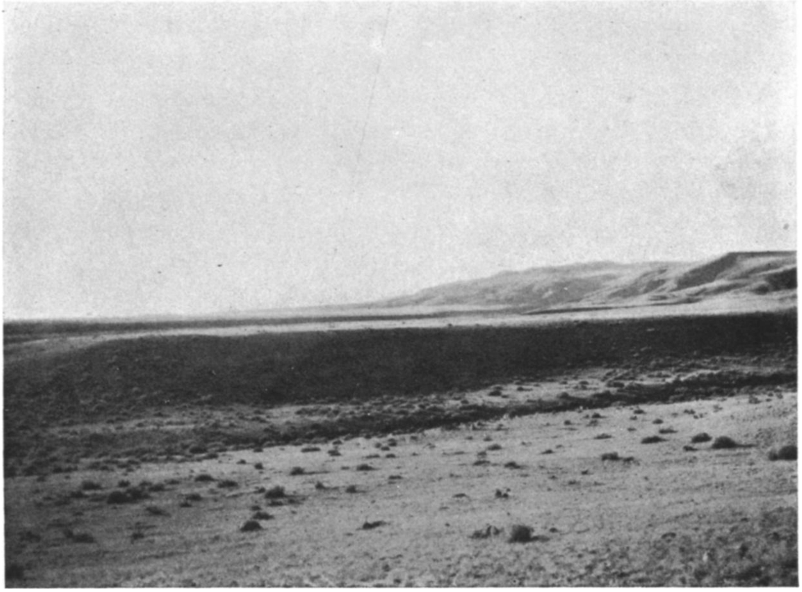

FIG. 24.—Plane surfaces developed upon the Wind River Eocene beds on the flanks of Black Mountain, in the Wind River basin.

In the notably weak beds of Tertiary and Cretaceous age, broad plains have been developed at elevations several thousand feet below the surrounding highlands (Fig. 24). Good examples of these are the Wind River basin, Jackson Hole, Teton basin, Bighorn basin, Green River valley, and many others outside the district here considered. In these wide basins the younger rocks, down to the more or less resistant Triassic(?) red beds, or even down to the Carboniferous terranes, have nearly all been planed off to a common level. It is highly probable, however, that all of the basins were formerly filled more or less completely with the soft Tertiary strata, and that most of the erosion has been accomplished in them rather than in the older rocks beneath. All are still partly filled with formations of that age, and outliers show a much more complete filling before erosion occurred.

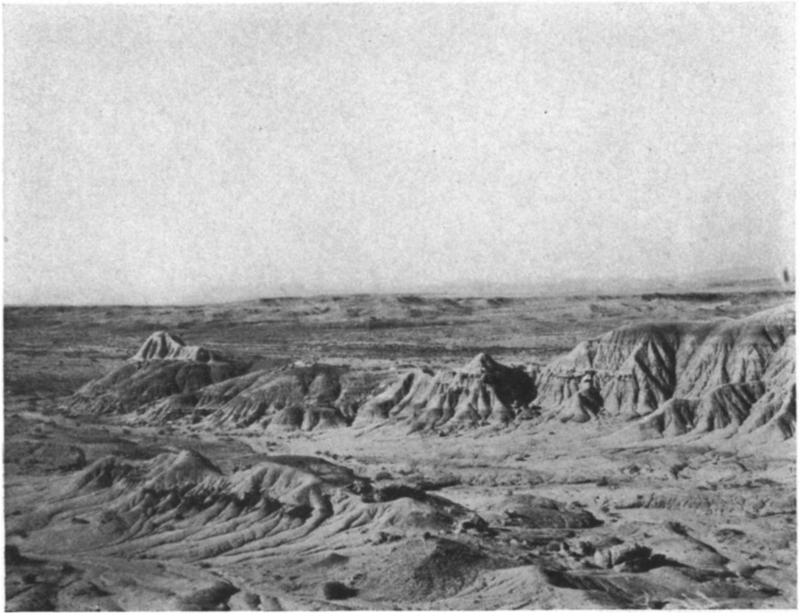

FIG. 25.—Bad-land topography in the Wind River basin. Shows dominance of the effects of running water even in the driest part of the district.

The floors of these basins are by no means simple flats (Fig. 25), but the details will be discussed more fully in later pages.

At the intertwined headwaters of the three great river systems, the valleys are still narrow and in part ungraded. There, even upon the soft Cretaceous and Tertiary beds, erosion has produced only a maturely dissected surface (Fig. 26). In this district the peneplain has been wholly destroyed, and it is improbable that any of the summits now rise to its former elevation.

In the moderately resistant limestones, sandstones, and interbedded shales, which constitute the Paleozoic sequence, erosion has proceeded much less rapidly than in the soft Mesozoic and Tertiary formations. Thus where the former rise to the surface we find them only maturely dissected into ramifying V-shaped valleys separated by skeleton ridges, or, where folded, into parallel mountains and valleys. The topography of the Gros Ventre Range and of the west slope of the Teton Range, as well as of mountains farther south along the state boundary, illustrates this phase of topographic development.

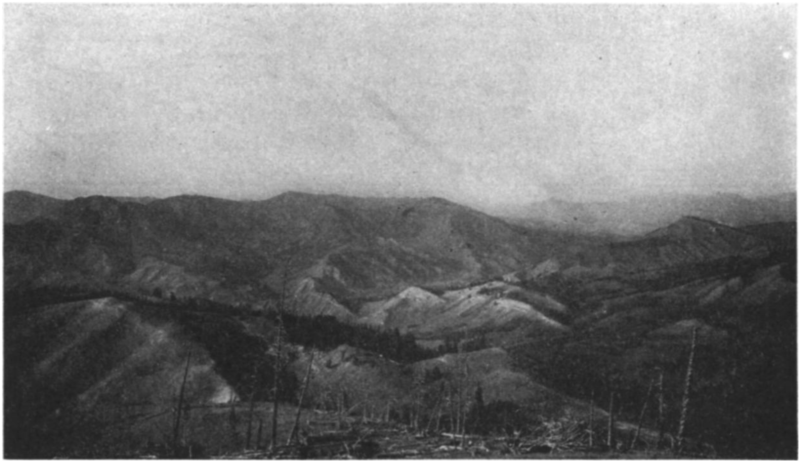

FIG. 26.—Mature topography developed on weak Cretaceous and Eocene strata along Fish Creek, near the Continental Divide.

Erosion has had the least effect upon the hard, massive, and tolerably uniform granites and gneisses of the pre-Cambrian complex. In the district under consideration there are but six localities where these ancient rocks reach the surface, and in three they have merely been uncovered in the bottoms of mountain canyons. The only expansive outcrops at high elevations are those in the Teton, Wind River, and Owl Creek ranges. In the Teton Range, the juxtaposition of very hard and very soft rocks along a fault has created abnormally steep slopes,[1] so that the Archean rocks of the

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[1] The magnificent east front of the Teton Range can scarcely fail to suggest to the geologist a recent fault scarp, but the consideration of it from various angles in three different seasons has convinced me that it is in fact a "fault-line scarp" (W. M. Davis, *Bull. Geol. Soc. Am.*, XXIV [1913], 187–216) situated along a Middle Tertiary displacement, of which the original topography has long since been destroyed. The facts which suggest a recent fault scarp are the abruptness and continuity of the wall, the comparative straightness of the base, and the triangular facets at the distal ends of the very short steep spurs. The gravel-strewn floor of Jackson Hole seems also to indicate the thick alluvial deposits normally made on the downthrown sides of new faults. On further consideration, however, it appears that all of these phenomena may be satisfactorily explained without assuming a recent fault, and there are additional facts which indicate that the scarp was produced by the exhuming of a once-buried fault surface. Such a scarp would be abrupt and continuous, and as straight as the fault trace. In the early stages of dissecting the scarp, triangular facets would be developed at the distal ends of the spurs. The alluvial filling of the Snake River valley is of unknown depth, but the exposures of the underlying rock in several parts of the floor of Jackson Hole suggest that there is only a veneer of alluvium, as in other basins in Wyoming. That the gravel is somewhat thicker in Jackson Hole than elsewhere may be due to the fact that glacial waters from the Jackson Lake moraine poured a large volume of outwash southward along Snake River. (See Fig. 27).

The facts which directly suggest that the fault is an old one, and the scarp due merely to the great contrast in the resistance offered by the rock masses on the east and west sides to erosion, are: (*a*) all other faults within 25 or more miles of this region are old faults, which have lost all original topographic expression; (*b*) it is particularly

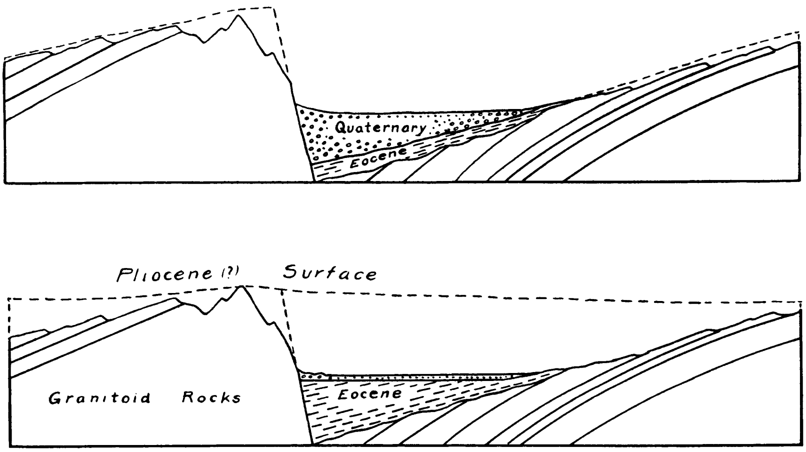

FIG. 27.—Diagrams of the Teton front to explain two possible origins of the escarpment: (*a*) as a modern normal fault scarp; (*b*) as a fault line scarp discovered entirely by erosion.

uplift have been eroded much more rapidly than they otherwise would have been. The Archean exposures of the Owl Creek Range are not large, and probably did not appear until the last two or three thousand feet of denudation were accomplished. We are reduced, therefore, to a consideration of the Wind River Range as the only part of the district in which the Archean rocks are broadly exposed and under simple conditions. The Bighorn, Sherman, and certain other ranges in the state should probably be put in the same category.

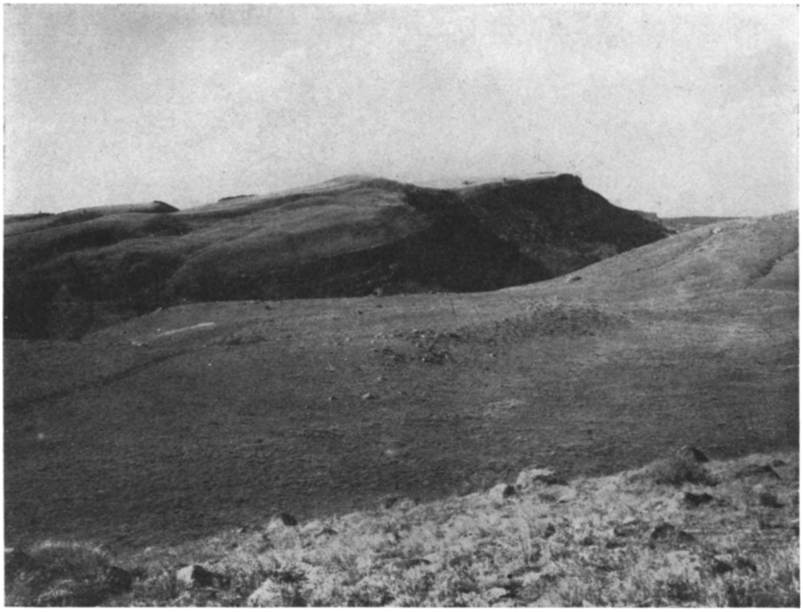

FIG. 28.—A typical canyon in the hard Carboniferous rocks of the Wind River Range, twelve miles west of Lander.

significant that this is true of the Phillips Canyon fault which appears to join the main Teton fault at an acute angle as if it were merely a branch of it; (*c*) sedimentary rocks to a thickness of perhaps more than 10,000 feet have been removed from the Teton, block since it was first elevated, but these are still preserved in the bottom of Jackson Hole; (*d*) the abruptness and height of the escarpment decrease immediately and markedly toward the north and south ends of the range, as quickly as the outcrops of the less resistant Paleozoic and Mesozoic strata are reached; (*e*) the flat-bottomed part of Jackson Hole coincides almost exactly with the distribution of the weakest Eocene clays and the valley becomes narrow again southward as soon as the Cretaceous outcrops are reached.

In the Wind River uplift deep canyons have been carved out of the granitic rocks, but extensive remnants of the old plateau surface are still preserved upon the interstream divides (Fig. 12). The relative resistance of the hard Archean outcrops is well shown in the channels of many of the creeks that flow out from the Wind River Range. Thus it is generally easy to ascend these valleys as far as they have been cut through the sedimentary strata, but from the base of the Cambrian inward to the axis of the anticline, the Archean outcrop is marked by a series of rapids, falls, and narrow gorges which make even foot travel difficult if not impracticable. Along old faults, which have brought the Archean into contact with some of the weaker members of the sedimentary column—as for example south of the great bend of Green River—the streams have cut merely a few notches in the pre-Cambrian rocks during the time in which the softer sedimentary beds have been completely stripped away to a much lower elevation. This satisfactorily explains why the Wind River plateau has an abrupt front in this locality but not elsewhere.

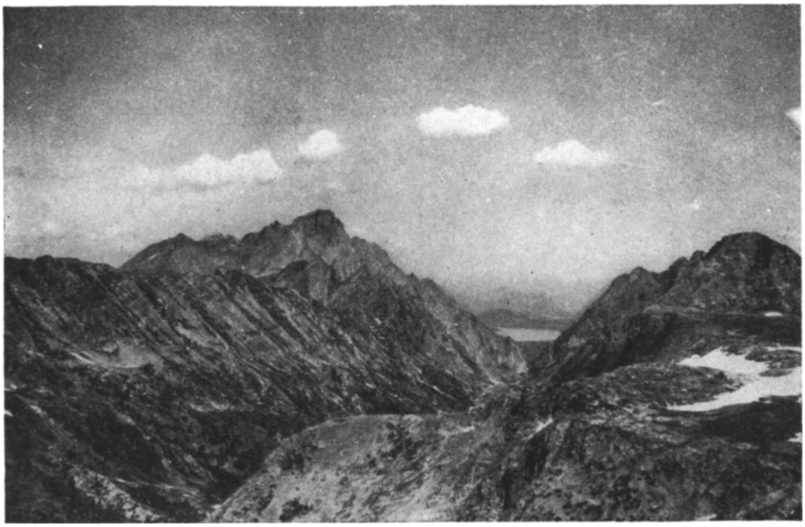

FIG. 29.—A canyon in the Archean rocks south of Mount Moran, in the Teton Range.

In short, it appears that the Quaternary has been characterized by widespread changes of level, which in turn have induced the erosion of deep valleys, and that these valleys have been widened in proportion to the weakness of the strata in which they were carved (Figs. 28 and 29). Although there is an advantage in stating the history in these simple terms in order to display the general conditions, it is appropriate to say that the events of the Quaternary have been much more varied and complex than this generalized statement implies. There is good evidence that the uplift or other interruption did not take place once for all at the beginning of the period, nor uniformly throughout the period, but at intervals scattered through a long time. Denudation has been accented by these disturbances, and doubtless also by climatic changes, of which mention has not yet been made. Furthermore, the work of denudation has been done, not only by streams, but in minor degree also by winds, glaciers, avalanches, ground-water, and unaided gravity. This complex chapter of the history may now be analyzed; and, since the changes produced by the different agencies are not in all cases readily correlated, I find it best to treat them separately and in the order of their relative importance.